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The Establishment of Exterior Windows Energy Saving Index System in Hot Summer and Cold Winter Region

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(Abstract) The exterior windows are the weakest links of heat insulation in building envelop. The evaluation of the windows energy-saving is an important research topic. This paper respectively used the fuzzy comprehensive evaluation method and grey correlation evaluation method to evaluate whether the window is energy-saving, from the results can be seen, both of the two methods have some significance in the actual windows energy-saving transformation. But the disadvantage of these methods is influenced by the subjective factors. By contrast, the grey correlation evaluation method is objective and it is more suitable to evaluate the windows energy-saving.

Keywords: Windows Energy-saving; Evaluation Index System; Fuzzy Comprehensive Evaluation Method; Grey Relation Evaluation Method.

1. Introduction

In building energy consumption, most of the consumption is caused by building envelop exchanging heat with outdoor environment, while the exterior windows are the weakest links of heat insulation in building envelop. The amount of heat consumption(including the cold wind penetration、radiation heat transfer and conduction heat loss) take up about 50% of the total heat consumption of building envelop, Therefore, it is important to reduce the heat consumption of the exterior windows in building energy conservation work [1].

According to information from Britain, the United States, Japan and other countries, they have established the comparatively perfect evaluation systems. Such as British research establishment environmental assessment method(BREEAM)[2], American leadership in energy and environmental design(LEED)[3], Japanese comprehensive assessment system for building environmental efficiency(CASBEE)[4]. To establish and improve building energy efficiency evaluation system in China, this article makes a simple review about the energy saving technology evaluation system of the windows in hot summer and cold winter zone.

2. The Establishment of Exterior Windows Energy Saving Index System

The energy efficiency evaluation index of exterior windows have a lot of the sources, this paper is mainly from three aspects to get evaluation index[13]: 1) Refer to the existing the international fashional exterior window environment and the evaluation methods; 2) Observe our country's current standards of the exterior windows energy-saving technology; 3) Read scientific papers about the exterior windows energy-saving evaluation system .Based on the above, this paper sum up the energy efficiency evaluation index. The index selected and confirmed, need to combined with the current relevant the energy conservation policy regulations of the window and technical standards which can ensure the practicality and operability.

Based on the above three index sources, and according to the following principles screen and refine [12]: 1) Data accessibility. 2) Systematicness. 3) Effectiveness. 4) Multi-criteria decision rules. This paper establishes a evaluation system about the design of the exterior windows and operation in hot summer and cold winter area which is shown in table 1.

Table 1. The comprehensive energy-saving index system and weights of the exterior window

Target level	rule level (level 1)	weight	Index level (level 2)	weight	total goal weight
The comprehensive energy-saving index of the windows A	the windows' thermal performance B^1	w^1 (0.5713)	the windows' heat transfer coefficient C_1^1	w_1^1 (0.2266)	0.1295
			air impermeability C_2^1	w_2^1 (0.2120)	0.1211
			the windows' solar heat gain coefficient C_3^1	w_3^1 (0.1330)	0.0760
			visible light transmittance C_4^1	w_4^1 (0.1244)	0.0711
			area ratio of window to wall C_5^1	w_5^1 (0.1571)	0.0897
			shading coefficient C_6^1	w_6^1 (0.1469)	0.0839
	the windows' technology and quality control B^2	w^2 (0.2567)	the windows' materials C_1^2	w_1^2 (0.2323)	0.0596
			the windows' shade measures C_2^2	w_2^2 (0.3033)	0.0779
			production technology difficulty of energy-saving windows C_3^2	w_3^2 (0.1557)	0.0400
			the windows' install difficulty C_4^2	w_4^2 (0.1193)	0.0306
			the method of opening and closing the windows C_5^2	w_5^2 (0.1010)	0.0259
			Related complete set technology of adaptability C_6^2	w_6^2 (0.0884)	0.0227
	the windows' economy index B^3	w^3 (0.1721)	energy-saving investment C_1^3	w_1^3 (0.2923)	0.0503
			energy-saving income C_2^3	w_2^3 (0.4983)	0.0857
			maintenance costs C_3^3	w_3^3 (0.2094)	0.0360

3. Energy Saving Technology Evaluation Method of the Exterior Windows in Hot Summer and Cold Winter Zone

3.1. Fuzzy Comprehensive Evaluation Method

The fuzzy comprehensive evaluation method [5], which can divide complex problems into several levels and index, and assign the weights according to the importance, also can score each index to analyze the whole problem by the method of combining qualitative and quantitative aspects, make a comprehensive evaluation by combining all aspects of the exterior windows energy-saving.

3.1.1. The Established Fuzzy Comprehensive Evaluation Index System of the Exterior Windows Energy-Saving

Table 1 has set up the window energy-saving evaluation index system. From table 1, you can collect evaluation factors sets of the window comprehensive evaluation system:

$$A = (B^1 \quad B^2 \quad B^3)$$

Type:

$$\begin{aligned} B^1 &= (C_1^1 \quad C_2^1 \quad C_3^1 \quad C_4^1 \quad C_5^1 \quad C_6^1) \\ B^2 &= (C_1^2 \quad C_2^2 \quad C_3^2 \quad C_4^2 \quad C_5^2 \quad C_6^2) \\ B^3 &= (C_1^3 \quad C_2^3 \quad C_3^3) \end{aligned} \tag{1}$$

3.1.2. AHP Analyses the Model of Weights

Step 1: Through the questionnaire survey of each individual experts judge the exterior windows index weights, structure the judgment matrix;

Step 2: Through the hierarchical analytic model of weights, combine the individual judgment matrix to the expert panel's judgment matrix;

Step 3: Calculate evaluation index' weights.

Step4: Check the consistency [6]. The smaller the consistency, the consistency of judgment is higher and the reliability of the results is higher.

3.1.3. Ensure the Exterior Windows' Comprehensive Energy-saving Levels

(1) According to the above four steps, use the analytic model of weights and the expert panel's judgment matrix, get the weights of the exterior windows' evaluation indexes .

$$\begin{aligned} &w = (w^1 \quad w^2 \quad w^3) \\ &type: \\ &w^1 = (w_1^1 \quad w_2^1 \quad w_3^1 \quad w_4^1 \quad w_5^1 \quad w_6^1) \\ &w^2 = (w_1^2 \quad w_2^2 \quad w_3^2 \quad w_4^2 \quad w_5^2 \quad w_6^2) \\ &w^3 = (w_1^3 \quad w_2^3 \quad w_3^3) \end{aligned} \tag{2}$$

(2) Set evaluation scale sets $V=\{v_1, v_2, v_3, v_4, v_5\}$, they successively express "optimal"、"comparatively optimal"、"general"、"inferior" and "bad", correspond to the score sets (0.9, 0.7, 0.5, 0.3, 0.1). According to the grades of each member of evaluation experts group, get the judgment matrix of all evaluation factors by normalizing :

$$R^1 = (r_{ij}^1)_{6\times5}, R^2 = (r_{ij}^2)_{6\times5}, R^3 = (r_{ij}^3)_{3\times5} \tag{3}$$

(3) Find out the corresponding comprehensive evaluation results of the evaluation factors B^1、B^2 and B^3:

$$D^i = w^i R^i (i = 1,2,3,4,5) \tag{4}$$

(4) By steps (4), get the corresponding evaluation matrix of the level 2's evaluation factors set v:

$$R = \begin{pmatrix} D^1 \\ D^2 \\ D^3 \end{pmatrix} \tag{5}$$

(5) Eventually get the exterior windows' energy-saving evaluation result:

$$D = w \circ R = (d_{ij}) = \bigvee_{k=1}^{n} (w_{ik} \wedge r_{ki}) \tag{6}$$

(6) The comprehensive energy-saving level of the exterior window:

$$N = D \circ V = (d_1 \quad d_2 \quad d_3) \begin{pmatrix} v_1 \\ v_2 \\ v_3 \end{pmatrix} \tag{7}$$

3.2. Grey Relation Evaluation

Grey relation evaluation method [8] includes the following calculated and analysis steps:

(1) Ensure the reference sequence and sample sequence, as type (8) shows:

$$X_j = \{X_j(1), X_j(2), \cdots X_j(m), \cdots, X_j(n)\}, \tag{8}$$

Type: $X_j(m)$ - the value of the m[th] factor of the j[th] system.

Establish hierarchical analytic model of weight, get the weights of all factors in the sample sequence. Then, ensure the reference sequence, as type (9) shows:

$$X_0 = \{X_0(1), X_0(2), \cdots, X_0(m), \cdots, X_0(n)\}, \quad (9)$$

Type: $X_0(m)$ -the reference of the m[th] factor in the system.

The energy-saving assessment level is divided into 5 levels {Optimal; Comparatively excellent; General; Inferior; Bad}. Some data are hard to get directly from the ready-made standards or regulations, need to combine the language to describe or through the survey scoring method, divided into five levels [9].

(2) Transform original data

Generally use interval threshold to transform the original data of index series in the paper, so respectively suppose the sample sequence and reference sequence as $\tilde{X}_j$ and $\tilde{X}_0$ after the interval threshold transformed. For example the calculation of reference sequence X_0 show as type (10):

$$\tilde{X}_0(m) = \frac{X_0(m) - \min X_0(m)}{\max X_0(m) - \min X_0(m)} \quad (10)$$

(3) The absolute difference sequence

The absolute difference sequence Δ_{j0} is the approach degree between the sample sequence $\tilde{X}_j(m)$ and the reference sequence $\tilde{X}_0$, as type (11) shows:

$$\Delta_{j0} = \left| \tilde{X}_j(m) - \tilde{X}_0(m) \right| \quad (11)$$

Among them, the maximum and minimum sequence respectively are $\Delta_{\max}$ and $\Delta_{\min}$, as type(12) shows:

$$\begin{cases} \Delta_{\max} = \max\limits_j \max\limits_n \{\Delta_{j0}(m)\}, \\ \Delta_{\min} = \min\limits_j \min\limits_n \{\Delta_{j0}(m)\}. \end{cases} \quad (12)$$

(4) Correlation coefficient

The calculation of Correlation coefficient shows as type (13):

$$\xi_{j0}(m) = \frac{\Delta_{\min} + \rho\Delta_{\max}}{\Delta_{j0}(m) + \rho\Delta_{\max}} \quad (13)$$

Type: ρ-distinguish coefficient, value [0, 1], generally take 0.5.

(5) Degree of correlation

The degree of correlation r_{j0} between the j[th] system and the sample system that defined of reference sequence, as type (14) shows:

$$r_{j0} = \sum_{k=1}^{n} w_j(m) \cdot \xi_{j0}(m), \quad (14)$$

Type:--the weight coefficient between $w_j(m)$ and the correlation coefficient $\xi_{j0}(m)$.

(6) The gray relevancy order

According to the size of the gray relevancy, order them and then analyze advantage. If $r_{\max}=\max(r_{j0})$, then the j[th] system is most similar to the corresponding situation of the reference sequence.

3.3. The Example Analysis

Research the typical city Nanjing in hot summer and cold winter area, analyze one newly-built building. Because the Windows have 8 towards (north (N), northeast (NE), east (E), southeast (SE), south (S), southwest (SW), west (W), northwest (NW)), and all them influence the energy saving, but if consider all towards, the evaluation process will become quite complex. So this text only consider south window. Establish hierarchical structure model, as table 1 shows.

(1) Through the above four steps, combine the analytic model of weights with the expert judgment, I got the evaluation index' weights of exterior windows as what table 1 shows.

(2)Respectively use fuzzy comprehensive evaluation method and grey correlation assessment method to calculate

Fuzzy comprehensive evaluation method:

①The energy-saving evaluation result of the exterior windows

$$D = w \circ R = (0.5237 \ 0.2567 \ 0.0674 \ 0.0070 \ 0)$$

②The comprehensive energy level of the exterior windows

$$N = D \circ V = 0.6868$$

grey correlation assessment method

①Secondary correlation r_{j0}

$$r_{j0}=\sum_{k=1}^{n}w_j(m)\cdot\xi_{j0}(m)=\begin{Bmatrix}0.7024 & 0.8455 & 0.7444 & 0.5332 & 0.4075\\ 0.7693 & 0.4800 & 0.6377 & 0.4796 & 0.3853\\ 0.6 & 1 & 0.6 & 0.429 & 0.333\end{Bmatrix}$$

②Correlation r

$$r=\sum_{k=1}^{3}r_{j0}(k,i)\cdot w'(k)=\begin{pmatrix}0.7020 & 0.7784 & 0.6922 & 0.5016 & 0.3890\end{pmatrix}$$

(3)Analyze the results

① $N=0.6868$ close to the level "the better" which is 0.7, so the evaluation result is optimal.

From the correlation r can be seen, the second data is the biggest, that is the sample matrix is most close to the second column data of reference matrix, so the corresponding level of the window belongs to the second level-comparatively good. Both of them are consistent, showing that this method is feasible on evaluation of the window energy-saving.

②Look from the sources of index, both of them are basically consistent; from the process of calculation, I found the grey correlation assessment is more complex, and is need to establish reference matrix and calculate the correlation between the sample matrix and reference matrix.

③The establishment of the former D is related to R, but R is gotten by the expert scoring and normalizing, so this has a lot of relevance with the experience of the experts, and the results are influenced by the subjective factors; The latter correlation r is calculated by the reference standard, objectivity is stronger.

Comprehensive concluded that the grey correlation evaluation is more suitable for the exterior windows energy-saving assessment

4. Conclusion

Through analysis and comparison, get the following conclusion:

(1)According to the characteristics of the windows, choose the fuzzy comprehensive evaluation method is more applicable to evaluate the exterior windows energy-saving. Use AHP to determine the weights and to evaluate the window energy-saving when has divided the evaluation unit. This paper also adopts AHP- Gray relational method to evaluate the window. From the example can be seen that this method used in the evaluation is feasible. Firstly, we need to establish the correct sets of evaluation factors and reference matrix which decide the applicable scope of evaluation model and the correctness of the evaluation; then determine the weights. Finally, analyze the relevancy order and determine the influence factors.

(2)Fuzzy comprehensive evaluation method has lots of arbitrariness and subjective judgment factors, its result largely depends on the quality of evaluation experts from the definition of evaluation sets、especially the structure of membership functions and the selection of composition operator to the selection of weights and the process of outputing evaluation results.

(3)The determination of weights is also affected by the subjective factors in the grey correlation method. But there are some differences in evaluation standards. The grey correlation method has less subjective factors, and as long as make some matrix of the reference standard interval, can evaluate more conveniently and visually.

(4)Through the comparison of the two methods, the grey correlation with certain objectivity is more suitable to evaluate the exterior windows energy-saving than the fuzzy comprehensive evaluation method.

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